

USE OF YTTRIUM, ZIRKONIUM, LANTHANUM, CERIUM, PRASEODYMIUM AND/OR NEODYMIUM AS  
REINFORCING AGENT FOR AN ANTICORROSION COATING COMPOSITION

The present invention sets out to develop an anticorrosion coating for metal parts, preferably free of hexavalent chromium, that has improved anticorrosion properties.

5 The present invention applies to all types of metal parts, in particular in steel or cast iron or whose surface is formed of a layer of zinc or zinc alloy, which require high resistance to corrosion, on account of their intended use in the automotive industry for example. Anticorrosion coating compositions, free of hexavalent chromium, have already been recommended. Some of these compositions contain a particulate metal. The particulate metal, such as zinc and/or aluminium, is in  
10 suspension in the composition and provides the metal part with sacrificial protection against a corrosive medium. Aqueous anticorrosion coating compositions for example have been described for metal parts, containing a particulate metal, an appropriate solvent, a thickener and a binder formed of a silane. Particulate metal-based compositions have also been described whose storage stability and  
15 anticorrosion performance are improved through the incorporation of molybdenum oxide ( $\text{MoO}_3$ ) in the composition.

Within the scope of the present invention, the applicant has discovered that it is possible to improve the anticorrosion properties of compositions containing particulate metal by incorporating therein at least one element chosen from among  
20 yttrium, zirconium, lanthanum, cerium, praseodymium and neodymium, in the form of oxides or salts.

The anticorrosion performance of coating compositions containing particulate metal prove to be further improved when the above-cited elements are associated with molybdenum oxide.

25 The compositions containing particulate metal concerned by the present invention may be aqueous phase or organic phase compositions. They are recommended when high resistance to corrosion is required.

The subject of the present invention is therefore the use of at least one element chosen from among yttrium, zirconium, lanthanum, cerium, praseodymium and neodymium in the form of oxides or salts, as agent to reinforce the anticorrosion properties of an anticorrosion coating composition containing a particulate metal, in aqueous or organic phase, for metal parts.

A further subject of the invention is the use of at least one of the above-cited elements, optionally associated with molybdenum oxide  $\text{MoO}_3$ , as reinforcing agent for the anticorrosion properties of an anticorrosion coating composition containing a particulate metal, in aqueous or organic phase, for metal parts.

Without this interpretation being restrictive, it would seem that the presence of at least one of the above-cited elements makes it possible to reinforce the efficacy of the anticorrosion protection imparted by the particulate metal in the composition.

The particulate metal present in the composition is preferably added in powder form, of different geometric, homogeneous or heterogeneous structures, in particular spherical, laminar, lenticular forms or other specific forms.

The oxides or salts of the above-cited elements which are used as reinforcing agents for the anticorrosion properties of the composition, are generally in powder form whose particles have a  $D_{50}$  of less than  $20\text{ }\mu\text{m}$  (the value  $D_{50}$  means that 50% by number of the particles have a particle size of less than this value, and 50% by number of the particles have a particle size greater than this value). During the preparation of the coating composition, a prior particle grinding or dispersion step (to break up agglomerates into elementary particles) may be conducted so that the composition contains particles with a  $D_{50}$  of less than  $3\text{ }\mu\text{m}$ .

These oxides or salts may be fully soluble, partially soluble or completely insoluble in aqueous phase or organic phase. They may be in dispersed or solubilised form within the composition.

Yttrium salts are advantageously chosen from among yttrium acetate, chloride, formate, carbonate, sulfamate, lactate, nitrate, oxalate, sulfate, phosphate and aluminate ( $\text{Y}_3\text{Al}_5\text{O}_{12}$ ), and their mixtures.

Yttrium oxide is advantageously in the form  $\text{Y}_2\text{O}_3$ .

Yttrium is preferably used in oxide form.

The yttrium oxide  $Y_2O_3$  used to prepare the coating composition is generally in the form of particles having a size of between 1  $\mu m$  and 40  $\mu m$ , with a  $D_{50}$  of approximately 6 to 8  $\mu m$ . When preparing the coating composition, a prior particle grinding or dispersion step (to break up agglomerates into elementary particles) may be conducted so that the composition contains particles having a  $D_{50}$  of less than 3  $\mu m$ .

Zirconium salts are preferably chosen from among zirconium carbonate, silicate, sulfate, and titanate, and their mixtures.

Zirconium oxide is advantageously in the form  $ZrO_2$ .

Lanthanum salts are advantageously chosen from among lanthanum acetate, oxalate, nitrate, sulfate, carbonate, phosphate and aluminate ( $LaAlO_3$ ), and their mixtures.

Lanthanum oxide is preferably in the form  $La_2O_3$ .

Cerium salts are advantageously chosen from among cerium chloride, carbonate, acetate, nitrate, oxalate, sulfate, phosphate, molybdate ( $Ce_2(MoO_4)_3$ ) and tungstate ( $Ce_2(WO_4)_3$ ), and their mixtures.

Cerium oxide is advantageously in the form  $CeO_2$ .

Cerium is preferably used in the form of cerium chloride or  $CeO_2$ .

Praseodymium salts are advantageously chosen from among praseodymium carbonate, chloride, nitrate, oxalate and sulfate, and their mixtures.

Praseodymium oxide is advantageously in the form  $Pr_6O_{11}$ .

Neodymium salts are advantageously chosen from among neodymium carbonate, chloride, nitrate and sulfate, and their mixtures.

Neodymium oxide is advantageously in the form  $Nd_2O_3$ .

When the composition also contains molybdenum oxide  $MoO_3$  associated with one of the above-cited elements used as reinforcing agent for the anticorrosion properties of the composition,  $MoO_3$  is advantageously incorporated in essentially pure orthorhombic crystalline form, having a molybdenum content of more than around 60 % by weight.

Preferably, the molybdenum oxide  $MoO_3$  is in the form of particles having a size of between 1  $\mu m$  and 200  $\mu m$ .

Preferably, said reinforcing agent for the anticorrosion properties of the composition is associated with molybdenum oxide  $\text{MoO}_3$  in a weight ratio of  $0.25 < \text{anticorrosion property reinforcing agent} : \text{MoO}_3 < 20$ , preferably  $0.5 < \text{anticorrosion property reinforcing agent} : \text{MoO}_3 < 16$ , further preferably  $0.5 < \text{anticorrosion property reinforcing agent} : \text{MoO}_3 < 14$ .

Preferably yttrium oxide  $\text{Y}_2\text{O}_3$  is used in association with molybdenum oxide  $\text{MoO}_3$ . A further subject of the invention is the use of yttrium oxide  $\text{Y}_2\text{O}_3$  in association with molybdenum oxide  $\text{MoO}_3$  in a weight ratio of  $0.25 < \text{Y}_2\text{O}_3 : \text{MoO}_3 < 20$ , preferably  $0.5 < \text{Y}_2\text{O}_3 : \text{MoO}_3 < 16$ , further preferably  $0.5 < \text{Y}_2\text{O}_3 : \text{MoO}_3 < 14$ .

A further subject of the invention concerns anticorrosion coating compositions for metal parts, comprising:

- at least one particulate metal;
- a reinforcing agent for the anticorrosion properties of the composition, chosen from among yttrium, zirconium, lanthanum, cerium, praseodymium and neodymium, in the form of oxides or salts, optionally associated with molybdenum oxide  $\text{MoO}_3$ ;
- a binder; and
- either water, optionally associated with one or more organic solvents, or one or more organic solvents miscible *inter se*.

The coating composition contains at least one particulate metal, i.e. one or more particulate metals.

Advantageously, the particulate metal content lies between 10 % and 40 % by weight relative to the weight of the composition.

The particulate metal may be chosen from among zinc, aluminium, tin, manganese, nickel, their alloys, and their mixtures.

Preferably the particulate metal is chosen from among zinc, aluminium, their alloys and their mixtures. Preferably the alloys are chosen from the alloys of zinc and aluminium containing at least 3 % by weight aluminium, preferably 7 % by weight of aluminium, and the zinc and tin alloys containing at least 10 % by weight of tin.

The content of anticorrosion property reinforcing agent of the composition preferably lies between 0.5 % and 10 % by weight relative to the weight of the composition, preferably between 1 % and 8 % by weight relative to the weight of the

composition, further preferably between 1 % and 7 % by weight relative to the weight of the composition.

The reinforcing agent for the anticorrosion properties of the composition is advantageously yttrium, preferably in the oxide form  $Y_2O_3$ , or cerium preferably in the form of cerium chloride.

The reinforcing agent for the anticorrosion properties of the composition is advantageously associated with molybdenum oxide  $MoO_3$  in a weight ratio of  $0.25 < \text{anticorrosion property reinforcing agent} : MoO_3 < 20$ , preferably  $0.5 < \text{anticorrosion property reinforcing agent} : MoO_3 < 16$ , further preferably  $0.5 < \text{anticorrosion property reinforcing agent} : MoO_3 < 14$ .

The binder content preferably lies between 3 % and 20 % by weight relative to the weight of the composition. The binder may be of organic and/or mineral type in aqueous or organic phase. The choice of the binder depends on different criteria, among which is the baking temperature of the coating composition.

The binder is preferably chosen from among an alcoxylated silane, optionally organofunctionalised, such as  $\gamma$ -glycidoxypropyltrimethoxysilane or  $\gamma$ -glycidoxypropyltrimethoxysilane, a silicone resin, a silicate of sodium and/or potassium and/or lithium, a zirconate, a titanate, an epoxy resin, a phenoxy resin, an acrylic and their mixtures.

The binder may be associated with a crosslinking agent of phenolic type, aminoplast type, or dicyandiamide type. Acid catalysts may also be added in order to catalyse the crosslinking reaction.

If the composition is in aqueous phase, a colloidal silica may be used in association with resins, as binder.

If the coating composition is in aqueous phase, the liquid phase is formed of water and may also contain up to 30 % by weight of an organic solvent or a mixture of organic water-miscible solvents.

If the coating composition is in organic phase, the liquid phase is entirely made up of an organic solvent or a mixture of organic solvents miscible *inter se*.

The organic solvent or solvents are chosen in relation to the binder, so as to solubilise the latter or stabilise a dispersion thereof. The organic solvent or solvents are advantageously chosen from white spirit, alcohols, ketones, aromatic solvents

and glycol solvents such as glycol ethers, in particular diethyleneglycol, triethyleneglycol and dipropyleneglycol, acetates, polyethyleneglycol and nitropropane, and their mixtures.

5 The coating composition may also contain a thickener if the type of application so requires, if it is to be applied by dipping-centrifuging for example.

The content of thickening agent is advantageously less than 7 % by weight relative to the weight of the composition, preferably between 0.005 % and 7 % by weight relative to the weight of the composition.

10 The thickening agent is advantageously chosen from among the cellulose derivatives such as hydroxymethylcellulose, hydroxyethylcellulose, hydroxypropylcellulose or hydroxypropylmethylcellulose, xanthane gum, associative thickeners of polyurethane or acrylic type, silicas, silicates such as silicates of magnesium and/or lithium optionally treated, or organophilic clays, and their mixtures.

15 The coating composition may also comprise a lubricating agent in sufficient quantity to obtain a self-lubricated system, chosen in particular from among polyethylene, polytetrafluoroethylene, MoS<sub>2</sub>, graphite, polysulfones, synthetic or natural waxes and nitrides, and their mixtures.

20 If it is in aqueous phase, the coating composition may also contain other additives compatible with the binder, chosen from among an anti-foam agent such as Schwego foam (emulsified hydrocarbon) from Schwegman, a wetting agent such as an ethoxylated monylphenol or an ethoxylated polyalcohol, a surfactant agent such as Aerosol TR 70 (sodium sulfosuccinate) from Cytec, and a biocide such as Ecocide D<sub>75</sub> from Progiva, and a weak acid such as boric acid to adjust the pH of the  
25 composition.

In preferred manner, the coating composition contains the following ingredients:

- 10 % to 40 % by weight of at least one particulate metal;
- 0.5 % to 10 % by weight of an anticorrosion property reinforcing agent for the  
30 composition chosen from yttrium, zirconium, lanthanum, cerium, praseodymium and neodymium, in the form of oxides or salts, optionally associated with molybdenum oxide MoO<sub>3</sub>;

- up to 7 % by weight of a thickener;
- 3 % to 20 % by weight of a binder;
- up to 3 % by weight, preferably 0.05 % to 2 % by weight of a sodium and/or potassium and/or lithium silicate;
- 5 - up to 7 % by weight of one or more lubricating agents;
- 1 % to 30 % by weight of an organic solvent or a mixture of organic solvents;
- optionally 0.1 % to 10 % by weight of a weak mineral acid such as boric acid;
- optionally 0.01 % to 1 % by weight of an anionic surfactant; and
- water to make up to 100 %.

10 If the above-cited anticorrosion property reinforcing agent is associated with molybdenum oxide, the latter preferably represents 0.5 % to 2 % by weight of the composition.

Evidently, the present invention also extends to anticorrosion coatings applied to metal parts using the above-cited compositions.

15 Application may be made by spraying, dipping-draining or dipping-centrifuging, the layer of coating then being subjected to a baking operation (by convection or infrared for example) preferably conducted at a temperature of between 70°C and 350°C, for approximately 10 to 60 minutes, by convection.

20 According to one advantageous embodiment, the anticorrosion coating derives from an application operation involving, prior to the baking operation, a drying operation of the coated metal parts (by convection, or infrared for example), in particular by convection at a temperature in the region of 70°C for approximately 10 to 30 minutes on line.

25 Under these conditions, the thickness of the dry film so applied lies between 3  $\mu\text{m}$  (11  $\text{g/m}^2$ ) and 15  $\mu\text{m}$  (55  $\text{g/m}^2$ ), preferably between 4  $\mu\text{m}$  (15  $\text{g/m}^2$ ) and 10  $\mu\text{m}$  (40  $\text{g/m}^2$ ), further preferably between 5  $\mu\text{m}$  (18  $\text{g/m}^2$ ) and 10  $\mu\text{m}$  (40  $\text{g/m}^2$ ).

The present invention also extends to the metal substrate, preferably in steel, provided with an anticorrosion coating applied using the above-cited compositions.

30 This itself may be coated with another coating to further reinforce some properties, such as anticorrosion protection or lubrication. A coating to reinforce the anticorrosion protection may contain an alkaline silicate, in particular a sodium

and/or potassium and/or lithium silicate, an acrylic, a zirconate, a titanate, a silane, an epoxy resin, a phenol resin or one of their mixtures, these resins optionally being associated with a colloidal silica. A coating for lubrication may contain a lubricating agent chosen from among polyethylene, polytetrafluoroethylene, MoS<sub>2</sub>, graphite, polysulfones, synthetic or natural waxes, and nitrides, and their mixtures.

### Corrosion tests

- A) Influence of yttrium oxide (Y<sub>2</sub>O<sub>3</sub>), in aqueous phase, optionally associated with molybdenum oxide (MoO<sub>3</sub>) on anticorrosion performance.

Comparative experiments were conducted on the coating compositions given in table 1.

Table 1

| weight %                                   | composition |     |     |     |
|--|-------------|-----|-----|-----|
|  | 1           | 2   | 3   | 4   |
| Y <sub>2</sub> O <sub>3</sub> <sup>1</sup> | 0           | 3.0 | 0   | 3.0 |
| MoO <sub>3</sub>                           | 0           | 0   | 0.9 | 0.9 |
| Zinc <sup>2</sup>                          | 23.6        |     |     |     |
| Aluminium <sup>3</sup>                     | 3.0         |     |     |     |
| Silane A187 <sup>4</sup>                   | 10.1        |     |     |     |
| Sodium silicate 20N32 <sup>5</sup>         | 0.9         |     |     |     |
| Rempcopal® N4 100 <sup>6</sup>             | 1.4         |     |     |     |
| Rempcopal® N9 100 <sup>7</sup>             | 1.6         |     |     |     |
| Dipropylene glycol                         | 7.5         |     |     |     |
| Aerosil® 380 <sup>8</sup>                  | <0.1        |     |     |     |
| Schwego Foam® 8325 <sup>9</sup>            | 0.5         |     |     |     |
| Boric acid                                 | 0.8         |     |     |     |
| Deionised water                            | Up to 100 % |     |     |     |

<sup>1</sup> Y<sub>2</sub>O<sub>3</sub> of 99.99 % purity (Rhodia)

<sup>2</sup> Zinc in paste form, approx. 92 % in white spirit (80 % Alu Stapa PG Chromal VIII, from Eckart Werke)



<sup>3</sup> Aluminium, approx. 80 % in dipropylene glycol

<sup>4</sup>  $\gamma$ -glycidoxypolytrimethoxysilane (Crompton)

<sup>5</sup> Sodium silicate (Rhodia)

<sup>6</sup> Wetting agent of ethoxylated nonylphenol type (Uniqema)

5 <sup>7</sup> Wetting agent of ethoxylated nonylphenol type (Uniqema)

<sup>8</sup> Anti-sedimentation agent of silica type (Degussa)

<sup>9</sup> Antifoam of hydrocarbon type.

#### Prepared samples

- Treated substrate: degreased, shot-blasted steel screws
- 10 - Application of coating composition: dip-centrifuging
- Baking: 25 min at 310°C
- Weight of coating layer:  $26 \pm 2 \text{ g/m}^2$

The steel screws treated in this manner were tested with salt spray according to standard NFISO 9227. Results of salt spray resistance are given in table 2.

15

Table 2

| Composition | Y <sub>2</sub> O <sub>3</sub><br>(weight %) | MoO <sub>3</sub><br>(weight %) | Resistance to salt spray (N°<br>hours) |
|-------------|---|--------------------------------|--|
| 1           | 0   | 0                              | 140-260                                |
| 2           | 3   | 0                              | 840                                    |
| 3           | 0   | 0.9                            | 500                                    |
| 4           | 3   | 0.9                            | 1300                                   |

20 Table 2 clearly shows that the addition of yttrium oxide Y<sub>2</sub>O<sub>3</sub> to coating compositions increases resistance to salt spray in samples treated with these compositions.

Also, when yttrium oxide Y<sub>2</sub>O<sub>3</sub> is associated with molybdenum oxide MoO<sub>3</sub>, the anticorrosion performance is further improved. An interaction is observed or a synergy effect between Y<sub>2</sub>O<sub>3</sub> and MoO<sub>3</sub>, which increases the composition's anticorrosion performance.

25

B) Influence of zinc alloyed with 7 % aluminium (Stapa Zn<sub>4</sub>Al<sub>7</sub>, from Eckkart Werke) on anticorrosion performance.

Comparative experiments were conducted on the coating compositions listed in table 3.

5

Table 3

| composition |  |
|-------------|--|
| 5           | Identical to composition n° 3  |
| 6           | Identical to composition n° 4  |
| 7           | Identical to composition n°4 with the difference that 30 % by weight zinc is replaced by zinc alloyed with 7 % by weight of aluminium (Stapa Zn <sub>4</sub> Al <sub>7</sub> , from Eckart Werke). |

Prepared samples:

- treated substrate: degreased, shot-blasted steel screws
- Application of coating composition: dip-centrifuging
- 10 - Baking: 25 min at 310°C
- Weight of coating layer:  $26 \pm 2 \text{ g/m}^2$

The steel screws were treated with the coating compositions in table 3, then tested with salt spray according to standard NFISO 9227.

Results of resistance to salt spray are given in table 4.

15

Table 4

| Composition | Y <sub>2</sub> O <sub>3</sub><br>(weight %) | MoO <sub>3</sub><br>(weight %) | Stapa<br>Zn <sub>4</sub> Al <sub>7</sub> /Zn<br>(weight %) | Resistance to salt<br>spray (N° hours) |
|-------------|---|--------------------------------|--|--|
| 5           | 0   | 0.9                            | 0  | 450                                    |
| 6           | 3   | 0.9                            | 0  | 1370                                   |
| 7           | 3   | 0.9                            | 30   | 1900                                   |

Table 4 shows that the anticorrosion performance of the composition is better with alloyed zinc than with zinc.

20

C) Influence of cerium chloride in aqueous phase on anticorrosion performance

Comparative experiments were conducted on the coating compositions listed in table 5.

5

Table 5

| Composition |   |
|-------------|---|
| 8           | Identical to composition n° 3   |
| 9           | Identical to composition n° 1 with the difference that 0.5 % by weight of cerium chloride is added in addition to the other ingredients |
| 10          | Identical to composition n°1 with the difference that 2 % by weight of cerium chloride is added in addition to the other ingredients    |

Prepared samples

- Treated substrate: degreased, shot blasted steel screws
- Application of coating composition: dip-centrifuging
- 10 - Baking: 25 min at 310°C
- Weight of coating layer:  $26 \pm 2 \text{ g/m}^2$

The steel screws were treated with the coating compositions in table 5, then tested with salt spray in accordance with standard NFISO 9227.

The results of resistance to salt spray are given in table 6.

15

Table 6

| composition | Cerium chloride<br>(weight %) | Resistance to salt spray<br>(N° hours) |
|-------------|-------------------------------|--|
| 8           | 0                             | 200                                    |
| 9           | 0.5                           | 500                                    |
| 10          | 2                             | 770                                    |

Table 6 clearly shows that the addition of cerium chloride to coating compositions increases the resistance to salt spray of the samples treated with these compositions.

20

D) Influence of yttrium carbonate in aqueous phase on anticorrosion performance

Comparative experiments were conducted on the coating compositions listed in table 7.

5

Table 7

| Composition |  |
|-------------|--|
| 11          | Identical to composition n° 1  |
| 12          | Identical to composition n° 3 with the difference that 0.8 % by weight of MoO <sub>3</sub> is present in the composition instead of 0.9 %  |
| 13          | Identical to composition n° 2 with the difference that 3 % by weight of Y <sub>2</sub> O <sub>3</sub> are replaced with 6.9 % by weight of yttrium carbonate   |
| 14          | Identical to composition n° 4 with the difference that 3 % by weight of Y <sub>2</sub> O <sub>3</sub> are replaced with 6.9 % by weight of yttrium carbonate and 0.8 % by weight of MoO <sub>3</sub> are present in the composition instead of 0.9 % |

Steel screws were prepared, treated and tested as in example 1. Results of salt spray resistance are given in table 8.

10

Table 8

| composition | Yttrium carbonate (weight%) | MoO <sub>3</sub> (weight %) | Resistance to salt spray (N° hours) |
|-------------|-----------------------------|-----------------------------|-------------------------------------|
| 11          | 0                           | 0                           | 288                                 |
| 12          | 0                           | 0.8                         | 400                                 |
| 13          | 6.9                         | 0                           | 288                                 |
| 14          | 6.9                         | 0.8                         | 1296                                |

Table 8 clearly shows that, when yttrium carbonate is associated with molybdenum oxide MoO<sub>3</sub>, the anticorrosion performance is improved. An interaction is observed or a synergy effect between yttrium carbonate and MoO<sub>3</sub>, which increases the composition's anticorrosion performance.

15

E) Influence of various oxides in aqueous phase on anticorrosion performance

Comparative experiments were conducted on the coating compositions listed in table 9.

5

Table 9

| Composition |  |
|-------------|--|
| 15          | Identical to composition n° 1  |
| 16          | Identical to composition n° 3  |
| 17          | Identical to composition n° 2  |
| 18          | Identical to composition n° 4  |
| 19          | Identical to composition n° 2 with the difference that $Y_2O_3$ is provided by Sogemet                         |
| 20          | Identical to composition n° 4 with the difference that $Y_2O_3$ is provided by Sogemet                         |
| 21          | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $CeO_2$ provided by Rhodia    |
| 22          | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $CeO_2$ provided by Rhodia    |
| 23          | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $CeO_2$ provided by Sogemet   |
| 24          | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $CeO_2$ provided by Sogemet   |
| 25          | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $La_2O_3$ provided by Rhodia  |
| 26          | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $La_2O_3$ provided by Rhodia  |
| 27          | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $La_2O_3$ provided by Sogemet |
| 28          | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $La_2O_3$ provided by Sogemet |

|    |   |
|----|---|
| 29 | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $Pr_6O_{11}$ |
| 30 | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $Pr_6O_{11}$ |
| 31 | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $Nd_2O_3$    |
| 32 | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $Nd_2O_3$    |
| 33 | Identical to composition n° 2 with the difference that $Y_2O_3$ is replaced with $ZrO_2$      |
| 34 | Identical to composition n° 4 with the difference that $Y_2O_3$ is replaced with $ZrO_2$      |

## E-1) Electrochemistry

- Treated substrates : degreased and sanded steel plates,
- Application of coating composition : by means of a hand-coater,
- Baking : 25 min at  $310^\circ C$ ,
- Weight of coating layer :  $26 \pm 2 \text{ g/m}^2$ .

Polarisation resistance of the coatings was measured during one hour with SOLARTRON 1250 analyzer (Schlumberger), air exposed, with a scanning rate of  $\pm 10 \text{ mV}$  at  $0.1 \text{ mV.s}^{-1}$ . Results of these measurements are given in table 10. The higher the value of polarization resistance, the better the anticorrosion performance of the coatings is expected.

Table 10

| composition | Oxide           | Oxide (weight%) | $MoO_3$ (weight %) | Polarisation Resistance ( $\Omega.cm^2$ ) |
|-------------|-----------------|-----------------|--------------------|---|
| 15          | -               | 0               | 0                  | 3300                                      |
| 16          | -               | 0               | 0.9                | 9100                                      |
| 17          | $Y_2O_3$ Rhodia | 3               | 0                  | n.d.                                      |
| 18          | $Y_2O_3$ Rhodia | 3               | 0.9                | 12100                                     |

|    |  |   |     |       |
|----|--|---|-----|-------|
| 21 | CeO <sub>2</sub> Rhodia                | 3 | 0   | 10600 |
| 22 | CeO <sub>2</sub> Rhodia                | 3 | 0.9 | 12000 |
| 23 | CeO <sub>2</sub> Sogemet               | 3 | 0   | 10000 |
| 24 | CeO <sub>2</sub> Sogemet               | 3 | 0.9 | 12000 |
| 25 | La <sub>2</sub> O <sub>3</sub> Rhodia  | 3 | 0   | n.d.  |
| 26 | La <sub>2</sub> O <sub>3</sub> Rhodia  | 3 | 0.9 | 11900 |
| 27 | La <sub>2</sub> O <sub>3</sub> Sogemet | 3 | 0   | 9300  |
| 28 | La <sub>2</sub> O <sub>3</sub> Sogemet | 3 | 0.9 | 10100 |
| 29 | Pr <sub>6</sub> O <sub>11</sub>        | 3 | 0   | 9900  |
| 30 | Pr <sub>6</sub> O <sub>11</sub>        | 3 | 0.9 | 9800  |
| 31 | Nd <sub>2</sub> O <sub>3</sub>         | 3 | 0   | 9400  |
| 32 | Nd <sub>2</sub> O <sub>3</sub>         | 3 | 0.9 | 10000 |
| 33 | ZrO <sub>2</sub>                       | 3 | 0   | 9200  |
| 34 | ZrO <sub>2</sub>                       | 3 | 0.9 | 12000 |

Table 10 clearly shows that the addition of oxide of yttrium, cerium, lanthanum, praseodymium, neodymium or zirconium to coating compositions increases the polarization resistance of coatings, which indicates that the corrosion resistance of the coatings will be likely increased.

#### E-2) Corrosion resistance

Steel screws were prepared, treated and tested as in example 1. Results of salt spray resistance are given in table 11.

Table 11

| Composition | Oxide                                | Oxide (weight%) | MoO <sub>3</sub> (weight %) | Resistance to salt spray (N° hours) |
|-------------|--------------------------------------|-----------------|-----------------------------|-------------------------------------|
| 15          | -                                    | 0               | 0                           | 288                                 |
| 16          | -                                    | 0               | 0.9                         | 400                                 |
| 17          | Y <sub>2</sub> O <sub>3</sub> Rhodia | 3               | 0                           | 1056                                |
| 18          | Y <sub>2</sub> O <sub>3</sub> Rhodia | 3               | 0.9                         | >1500                               |

|    |  |   |     |       |
|----|--|---|-----|-------|
| 19 | Y <sub>2</sub> O <sub>3</sub> Sogemet  | 3 | 0   | 1296  |
| 20 | Y <sub>2</sub> O <sub>3</sub> Sogemet  | 3 | 0.9 | >1656 |
| 21 | CeO <sub>2</sub> Rhodia                | 3 | 0   | 144   |
| 22 | CeO <sub>2</sub> Rhodia                | 3 | 0.9 | 720   |
| 23 | CeO <sub>2</sub> Sogemet               | 3 | 0   | 144   |
| 24 | CeO <sub>2</sub> Sogemet               | 3 | 0.9 | 792   |
| 25 | La <sub>2</sub> O <sub>3</sub> Rhodia  | 3 | 0   | 336   |
| 26 | La <sub>2</sub> O <sub>3</sub> Rhodia  | 3 | 0.9 | 552   |
| 27 | La <sub>2</sub> O <sub>3</sub> Sogemet | 3 | 0   | 552   |
| 28 | La <sub>2</sub> O <sub>3</sub> Sogemet | 3 | 0.9 | 864   |
| 29 | Pr <sub>6</sub> O <sub>11</sub>        | 3 | 0   | 504   |
| 30 | Pr <sub>6</sub> O <sub>11</sub>        | 3 | 0.9 | 864   |
| 31 | Nd <sub>2</sub> O <sub>3</sub>         | 3 | 0   | 288   |
| 32 | Nd <sub>2</sub> O <sub>3</sub>         | 3 | 0.9 | 1560  |
| 33 | ZrO <sub>2</sub>                       | 3 | 0   | 288   |
| 34 | ZrO <sub>2</sub>                       | 3 | 0.9 | 456   |

Table 11 clearly shows that the addition of oxide of yttrium, lanthanum, praseodymium, neodymium or zirconium to coating compositions increases the resistance to salt spray of the samples treated with these compositions. The best oxide appears to be Y<sub>2</sub>O<sub>3</sub>, but Neodymium, Praseodymium and Lanthanum give also very good results too.

Furthermore, when the oxide is associated with molybdenum oxide MoO<sub>3</sub>, the anticorrosion performance is further improved. An interaction is observed or a synergy effect between the oxide and MoO<sub>3</sub>, which increases the composition's anticorrosion performance.